Simulation Analysis and Application of Hot Rolled Large Size H-beams

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***Abstract*- This paper studies a number of large size H-beams with the reference of the actual manufacturing process of H-beams at Laiwu iron & steel Group. The web cracking and cooling waves, as well as temperature field and rolling force, have been tested and analyzed, and the experiments on the performance and microstructure over the full section have been completed. With the help of building H-beams rolling finite element model, thermal mechanical coupled 3D numerical simulation of large size H-beams full rolling process has been realized, furthermore the residual stress transformation during cutting flange, as well as residual stress distribution of hot rolled H-beams, has been accomplished. The method of controlling residual stress has been achieved through numerical simulation. On the basis of the whole rolling process finite element simulations, with the help of the models of austenite evolution, phase transition and microstructure and property prediction, the simulation of 3D microstructure evolution and property prediction has been fulfilled. This paper provides the reference for the numerical simulation and application of hot rolled large size H-beams.**

***Keywords*- Large Size H-beams; Numerical Simulation; Residual Stress; Microstructure Evolution; Property Prediction**

I. INTRODUCTION

With the development of the numerical simulation technology, the utility of the simulation in the H-Beam rolling industry has been more and more universal. The simulation reproduces the material forming process, specifically it can calculate the strain, stress, the flowing of the metal, the change of the temperature, the evolution of the microstructure, the distribution of residual stress and the mechanical property. The successful usage of the simulation in the H-Beam hot rolling area has provided a reliable and convenient technical method for the development of the new products, the analysis of equipments breakdown, the defects of the product, the optimization and improvement of the design plan.

The rolling process of large size H-Beam has been studied in this paper. The simulation of the rolling process[1,2], residual stress[3,4], the transformation of the microstructure and the forecast of the property[5] have been elaborately demonstrated.

II. SIMULATION OF ROLLING PROCESS FOR LARGE SIZE H-BEAM

The rolling process of the large H-beam was calculated by FEM. Some of parameters were acquired from the simulation, including the metal flow status, stress field, strain field, rolling force and correlative energy parameters as well as the distribution of the temperature. The formation of the rolling work piece and the change of the temperature have been detected and illustrated, from which deduced the related transformation law, in order to instruct the process design and production.

A. Results of Structure Simulation

Based on the simulation of the H-Beam rolling process, we can obtain the distribution and change of stress and strain in different passes as well as under different forming situation at all spots and time. We can justify the forming status and the force distribution, which benefits the design of rolling grooves, from every part of the work piece by the outcome of structure simulation. Figure 1 is the strain field of the large H-Beam quarter section. It is quite clear that the connection area of the flange and web experiences highest strain during rolling. Figure 2 is the stress contour in the pressing direction of horizontal roller during the rolling process, which shows that the highest stress is located in the connection area of flange and web during rolling.

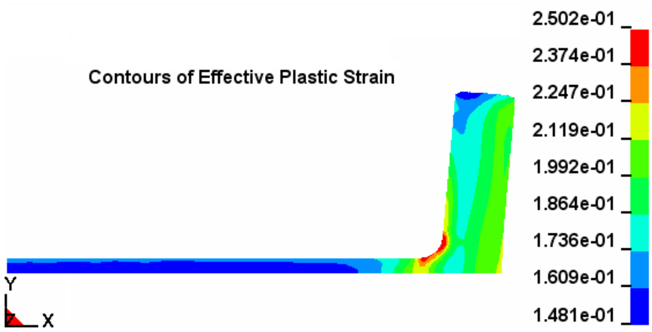


Fig. 1 Strain field of large H-Beam quarter-section after rolling（X Groove）

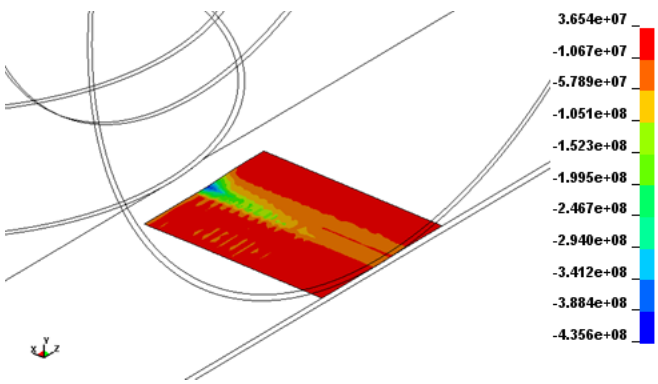


Fig. 2 Stress contour in the pressing direction of horizontal roller

B. Results of Metal Flow

During the rolling of the H-beam, the status of metal flow in different parts determines final shape and dimension of the product. We can directly instruct the design of the grooves and process by simulation results. Figure 3 shows the displacement vector of the metal flow in the flange stretching direction (y direction) during rolling. It can be easily

concluded that the outer side of the flange flows toward top of the flange and the inner side of the flange flows toward the connection area of flange and web which is flow along the curve of horizontal roller. This reverse phenomenon shows that as an integrated work piece there is some sort of metal flow in the section of the H-beam in order to make up the difference of the stretching between the web and flange.

Figure 4 shows the velocity field of metal flow in the rolling direction across the section of work piece, when it passes through the universal mill. During the rolling of H-Beam, since the vertical roller is driven roller, it hinders the metal flow forward passively, which is more obvious with increasing roller pressing. The hindrance from the vertical roller leads to the reduction of forward slip zone, and the extension of backward slip zone.

The flange and web of H-Beam should not be simply separated when studying the forward and backward slip zone during the rolling process. Since the stretching ratio of web and flange has a great influence on the slip zone, it is important to analyse it as a whole.

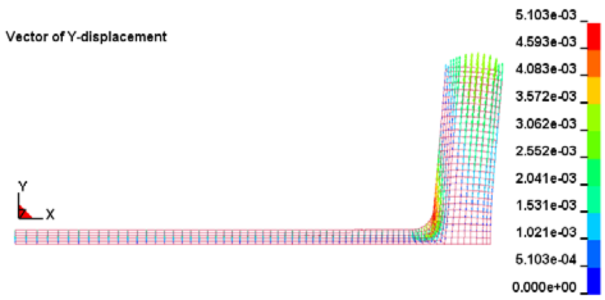


Fig. 3 Vector of metal flow in the H-Beam section （X Groove）

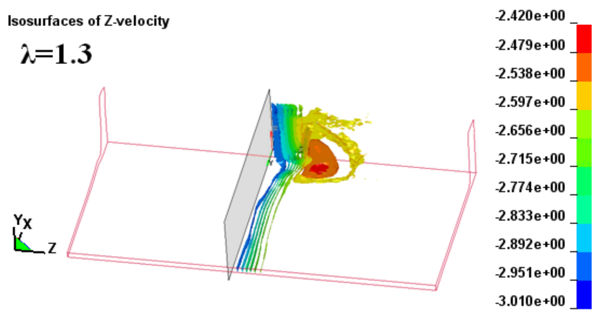


Fig. 4 Contour of metal flow in the H-Beam section（X Groove）

C. Results of Temperature Simulation

There are several factors that influence the temperature variation throughout the workpiece during H-Beam rolling. These factors includes: (1) The surface-to-volume ratio is different in various parts of workpiece. The web always has the highest surface-to-volume ratio, whereas in the flange it is relatively lower and the connection area of the web and flange has the lowest percentage. Because of that, the heat radiation status varied significantly in different parts of the section during rolling of the H-Beam. (2)The rolling temperature is relatively low. The surface area of workpiece which contacts to the roller, has an extremely drop of temperature, due to the heat conduction. (3)In the deformation zone the plastic work converts to the heat, so the temperature of some key points in the work piece has increased. (4)Because of the complexity of the H-Beam shape, the cooling water for the roller has accumulated in the tank space between both sides of flange. As a result, cooling water directly cools down the web, which is the main reason of the severely temperature difference in the section of large size H-beam. Figure 5 is the 3-D temperature contour of finish rolling. Figure 6 is the comparison of the temperature contour in the surface between simulation and measurement.

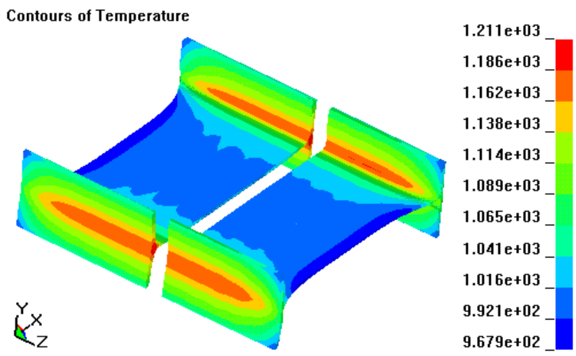


Fig. 5 Contour of finish rolling temperature field

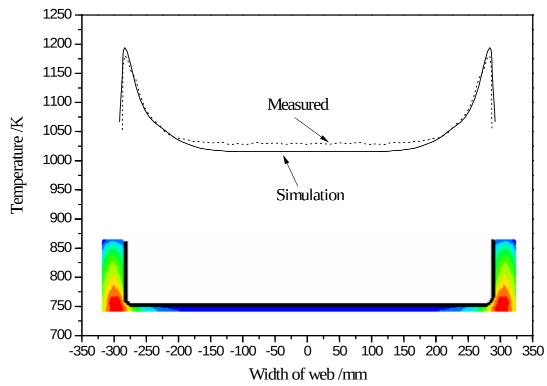


Fig. 6 Contour of the surface temperature large size H-Beam

The comparison between simulated and measured results shows that the temperature field of the H-Beam can be simulated with good accuracy. It is clear that the temperature curve of different parts generally drops during the rolling process. In addition, there is a turning point, which drops sharply, in each pass of the rolling at the position that contacts with the roller. But the surface of the work piece turns to the higher temperature when the deformation occurs. At the same time, some inner points of the work piece in the deformation zone have an increase in the temperature curve. Temperature difference in various points that located inside of the work piece reduces as the work piece goes slim, whereas the temperature difference on the surface becomes more and more manifested.

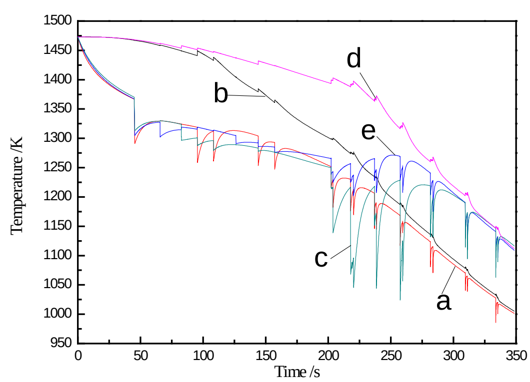


Fig. 7 Temperature curve of the key point in cross section

D. Results of Rolling Force

Figure 8 is the comparison between the calculated and measured rolling forces. Both horizontal and vertical rolling-force curves have the culmination at the inlet and the outlet spot of the rolling process. When the workpiece gets into the stable stage of rolling process, the rolling force is relatively steady. The simulation agrees with the testing date, which shows simulation method gives good description of the processes and can be extended as a foundation of fundamental study or further research. The simulated rolling force curves for different stretching ratio between flange and web are shown in figure 9. It can be concluded that the vertical rolling force increases and the drawing effect of the web has strengthened with increasing stretching ratio. As a result, horizontal rolling force decreases.

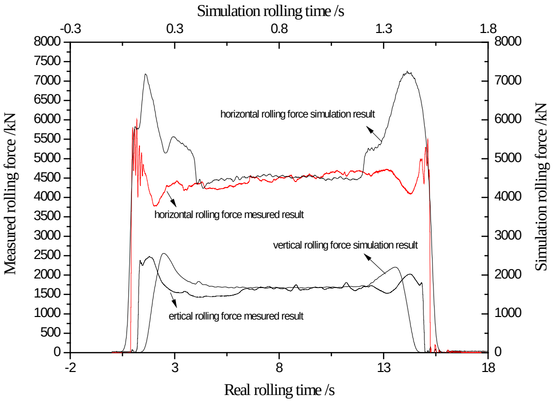


Fig. 8 Contrast of rolling force between the simulation and testing in a typical pass

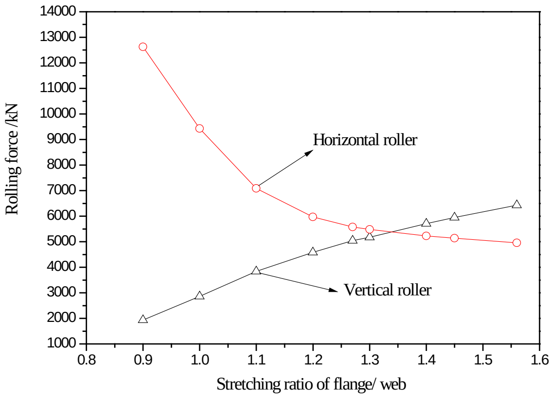
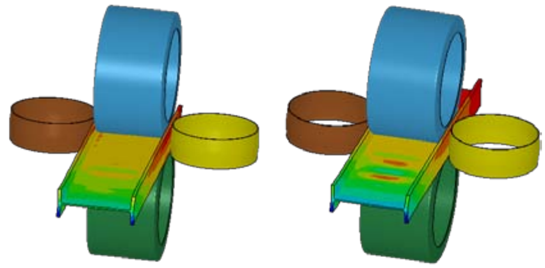


Fig. 9 Influence of the rolling force by the stretching ratio of flange/ web

E. Results of the Rolling Defect

The simulation for the abnormal rolling of the H-Beam is helpful for adjusting the process parameters and avoiding the defects of the products and the production accidents. Especially it can prevent the defects during the production such as the wave, the unsymmetrical of the web, deformation of flange, rising of both ends, bending and folded scratch. By means of numerical simulation, we can analyze the cause of the flaw, instruct the processes and prevent the defects.

Figure 10 shows the web waves generated during the rolling of the H-Beam. If the stretching ratio between the flange and web is not appropriate during rolling, especially when the amount of the web pressing is excessive, the additional compressive stress in the web become big enough to cause buckling and finally the web wave.



(a) (b)

Fig. 10 The simulation of web wave in different web / flange stretching ratio

Stretching ratio: (a) 0.94; (b) 0.92

III. Simulation of Residual Stress

This chapter emphasize on the inner residual stress of the large size H-beam which is caused by the difference of the temperature and heterogeneity of the metal flow in the section of H-Beam.

A. Residual Stress Simulation in Regular Status

Figure 11 is the residual stress contour of large size H-Beam with the length of 3m after rolling. Figure 12 is comparison between the simulation and the measurement. Figure 11-12 shows that the stress status of entire web is compressive, whereas the connection area of the flange and web is tensile stress, and the top of the flange is also compressive stress. The highest stress value in the web occurs in symmetry center of the H-beam. The workpiece in this dimension has the highest residual stress of more than 160 MPa in the web and more than 250 MPa in the connection area of flange and web.

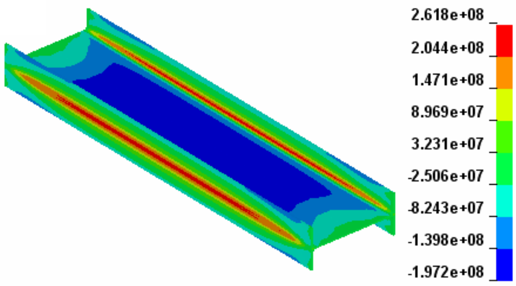


Fig. 11 Residual stress field of large H-Beam in the length direction

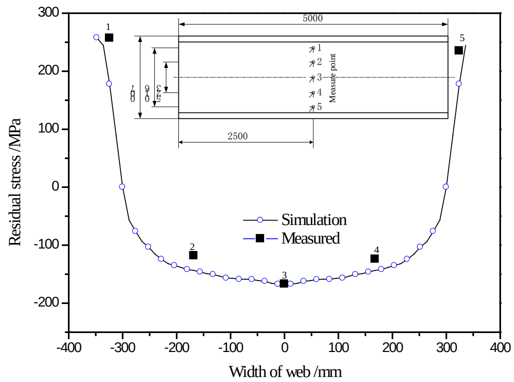


Fig. 12 Contrast of residual stress between simulation and measurement

B. Web Wave Simulation of Large Size H-beam

Due to temperature difference, the web has to bear the compressive stress during the cooling interval, which always leads to the cooling wave. Figure 13 is the simulation result of

the cooling wave in the web of large size H-beam during the cooling process.

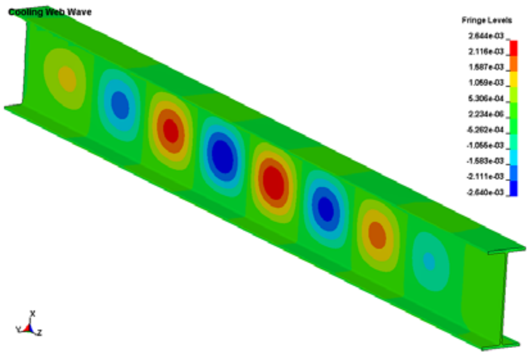


Fig. 13 Cooling wave in the web of large size H-beam

C. *Simulation of the Change of Residual Stress Field during Flange Cutting*

When the H-Beam is used in the steel structure, flange cutting sometimes leads to fractures or even cracking of the web due to the influence of the residual stress. In this sense, we can calculate the residual stress evolution during flange cutting by means of the numerical simulation method. The simulation results are shown in figure 14.

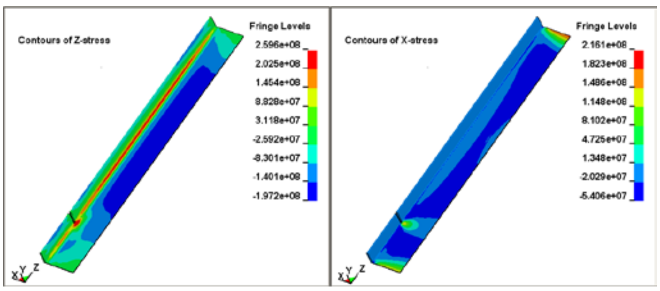


Fig. 14 Contour of the stress transformation in large H-beam during flange cutting

D. *Simulation for Residual Stress Control of Large H-beam*

It is imperative to control the residual stress, for the existence of the residual stress in large size H-Beam often causes problems. The interior residual stress of the large size H-Beam can be reduced by cooling the outside of the flange or control the temperature of the section at the last rolling pass. Figure 15 shows the comparison between the residual stresses before and after the cooling of the outer flange surface.

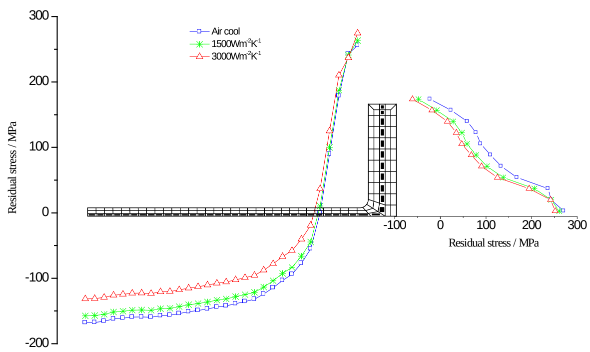


Fig. 15 Comparison between the residual stresses before and after the cooling of the outer flange surface

So we can propose new methods to control the residual stress and instruct processes by means of the numerical simulation method.

IV. Microstructure Evolution and Property Prediction of the Large Size H-Beam

Based on the thermal-mechanical coupled simulation of the full rolling process and physically-based models[6-8], it is possible to simulate the microstructure evolution and to predict the property. Figure 16 is the scheme for the microstructure simulation procedure[9].

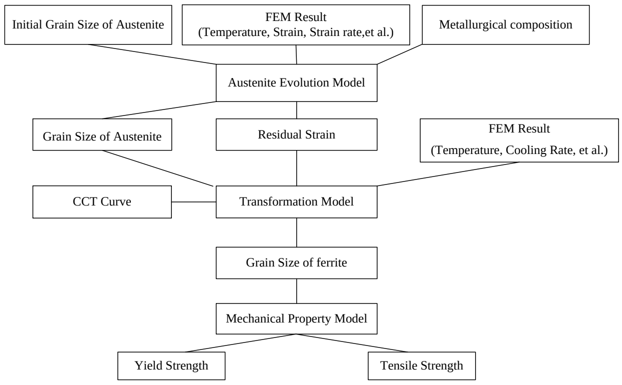


Fig. 16 Scheme for the microstructure simulation procedure

A. *Simulation of the Austenite Structure Transformation*

The grain size, residual strain and the recrystallization fraction could be calculated by basing on the thermal-mechanical coupling simulation of large size H-Beam full rolling process and combining metallurgical dynamic models for austenite transformation such as the dynamic recrystallization, metadynamic recrystallization, static recrystallization and the grain growth. Figure 17 depicts the distribution of the austenite grain size of Q235 large size H-beam.

Fig. 17 Contour of the Austenite grain size distribution after rolling

B. *Simulation of the phase transformation*

After the final rolling, the transition process of phase can be simulated, based on the result of the austenite size and temperature calculation during the cooling process, the phase transition model and CCT curve. Figure 18 illustrates the distribution of different ferrite grain size after the phase transformation of Q235 steel.

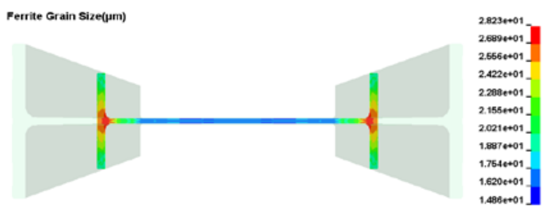


Fig. 18 Contour of the ferrite grain size distribution in the H-Beam section

C. *Property Prediction*

Based on the simulation result of phase transformation and the microstructure-property models, the yield strength, tensile strength and the hardness can be predicted. Figure 19 demonstrates the tensile strength distribution of the large size H-Beam section.

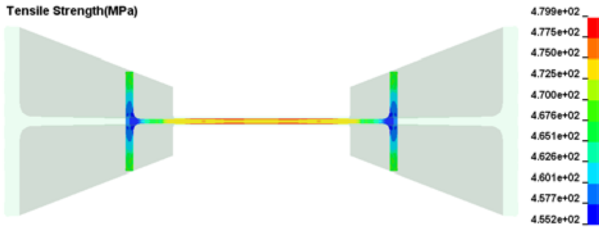


Fig. 19 Calculated result of tensile strength in H-beam section

V. CONCLUSIONS

This paper simulated the rolling process of large H-Beam, and studied the metal flow and the stress and strain field by means of the numerical simulation. It has provided valuable theoretical instructions for the deformation theory of the large section H-Beam.

The force and energy parameter such as rolling force and torque can be simulated with good accuracy. The results provide reliable references for the equipment checking and the process design.

While the defects of the rolling process were simulated, we could receive the defect simulation result under abnormal status during the rolling. The study can instruct the process of manufacture and provide reliable reference for improving the yield ratio as well as avoiding the product defects.

The residual stress simulation provided the solution and method for controlling the residual stress in the H-beam.

The simulation for predicting the microstructure evolution and property could provide the theoretical support for the design of large size H-beam. And it could foretell the properties of the product, when the product is in the early stage of designing.

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Guoming Zhu male, born in 1974, Ph.D, main research field is the simulation and utility of mechanical processing.